How Should Numerical Sediment Quality Criteria be Used?[1]

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The U.S. Environmental Protection Agency has published five numerical sediment quality criteria for the protection of benthic organisms. These criteria are derived from the equilibrium partitioning approach. While scientific discussion remains about the appropriateness of the approach and the method of derivation, the criteria represent, on a national basis, a numerical approach for regulating sediments as a contaminant source to the environment. Based on the methodology to derive the criteria and the stated use, protection of benthic organisms, how should such criteria be employed in the regulatory arena?

The best use of the criteria is the identification of sediments with specific contaminant concentrations above the criteria value. Sediments with contaminants exceeding the criteria are expected to produce some level of toxic effect on aquatic benthic organisms and a complete hazard assessment of such sediment should be performed. This does not mean that sediments with contaminant concentrations lower than the stated criteria are not impacted. First, because there are and will always be limits to the number of criteria available, contaminants that do not have criteria values may be present and impact the benthic community. Second, the present criteria are for individual compounds and therefore, do not address the interactions among the multiple contaminants that exist in essentially all field sites. Thus, a sediment with a concentration below the criteria value may still have adverse effects on the benthic community but the effects would not be identified by the criteria.

The second potential use of the criteria is for the regulation of open water disposal of dredged material. To be protective, sediments with contaminant concentrations that exceed the criteria values are expected to affect benthic organisms. Since the presence of multiple contaminants is the most likely scenario, exceeding a criteria should always indicate that a sediment is impacted. Even in the

unusual case that the criteria compound is the only one present, values above the criteria are expected to elicit a response. Therefore, once a sediment exceeds a criteria value, it can be presumed to produce effects with long-term exposures and should not be discharged into open water.

The criteria should not be used as cleanup criteria. Because the criteria do not account for interactions among existing compounds, single-compound values will not be adequate for defining when an area is sufficiently clean to protect the benthic organisms. Nor should such criteria be used to dictate whether or what type of site remediation *must* be performed. A complete hazard evaluation and risk assessment should be performed before selecting the best regulatory action for each particular site. Overall, the criteria are best used as flags which indicate problems, rather than strict values to dictate actions to be performed or avoided for a particular sediment.

Having indicated areas for which sediment quality criteria should and should not be used, are there any limitations of the criteria that restrict their use as suggested above? The criteria are organic carbon normalized values that account for differences in the bioavailability of sediments of differing organic matter concentrations. Carbon normalization does address some of the differences in toxicity among sediments of differing composition. However, for some non-polar organic compounds, carbon normalization has not completely removed the variability in expected toxic responses among sediments (Meyer et al., 1993). Organic carbon normalization did reduce the variability among sediments of measured LC50's on dry weight basis, but the range of LC50's remained a factor of three for a mixture of chloroethers. The range after carbon to normalization may well be smaller than reality due to analytical problems based on the range of interstitial water LC50's. A similar observation demonstrated that normalization by organic carbon will not always remove all the variability in bioavailability among sediments, measured as the uptake clearance, for sediment-associated polycyclic aromatic hydrocarbon and polychlorinated biphenyl congeners. The mean organic carbon normalized bioavailability varied by a factor of two when the source of the sediment was from Lake Michigan but the variation after carbon normalization varied a factor of nearly 10 when Florissant soil was used as an aquatic sediment (Landrum and Faust, 1994). The variation was the least for pyrene, a factor of approximately 3. Pyrene is a PAH with a log Kow of 5.2, essentially the same as fluoranthene. Thus, the expected variation in fluoranthene bioavailability, a compound with a proposed numerical criteria, would be expected to be similar under the same experimental design. Increasing the hydrophobicity of compounds is associated with increases in the variation in bioavailability after carbon normalization. All of the compounds with proposed criteria have log Kow values near or below that of pyrene. A two- to three-fold variation after carbon normalization may not be a major limitation, but it limits the strict application of the criteria without additional site assessment.

A criticism of the above work (Landrum and Faust, 1994) was the use of Florissant soil as an aqueous sediment, as this material accounted for most of the variation. Because, in many systems, sediment erosion may be a significant contributor to the existing sediment, the use of such material is not considered to be inappropriate. However, such soils may undergo alteration with time when

deposited in an aqueous environment and so the remaining variation may decline.

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In more recent work, the variation in bioavailability of compounds among a wide range of aquatic sediments with an organic carbon range of 0.45 to 21% on a dry weight basis was approximately a factor of nine for pyrene but was approximately a factor of twenty for more hydrophobic compounds, e.g. tetrachlorobiphenyl, hexachlorobiphenyl and benzo(a)pyrene, after normalizing for organic carbon (Landrum, unpublished data). Some of the samples exhibited additional enhanced bioavailability, similar to that observed for the soil sample above, and would have extended the variation to nearly a factor of 100. This order of magnitude variation remaining after carbon normalization for the majority of sediments suggests that the criteria be used conservatively, i.e., only for identifying areas of expected toxic impact. The hazard of a particular site should be evaluated through more extensive testing.

The criteria are supposed to evaluate the potential for chronic effects. However, no direct chronic tests have been performed to demonstrate that the criteria are appropriate under chronic conditions. The testing for validating the methodology has been of short duration, 10 days. The success of these ten day studies in validating the equilibrium approach may be fortuitous. Recent efforts to examine the accumulation of PAH and DDT from sediments suggest that long-term exposures may yield lower accumulation than would be observed over shorter exposure intervals, e.g. 10 days (Kukkonen et al., 1993; Brunson et al., 1993). One reason for lower accumulation with time for laboratory-dosed sediments was the long-term diffusion of the compound into inaccessible sites within sediment particles with the continued contact between the particle and compound (Landrum, 1989; Landrum, et al., 1992). An additional and perhaps more widespread cause for lower accumulation with long-term exposures may be a shift in the kinetics during the exposure. In the absence of animals, sediment for testing may well have an interstitial water concentration near equilibrium with sediment particles. With the addition of test organisms, organisms will rapidly accumulate the compound freely dissolved in the interstitial water. This rapid accumulation creates an observed peak in the accumulation. Subsequent accumulation occurs as a result of the accumulation through desorption from particles and accumulation from interstitial water and through particle ingestion and gut assimilation (Kukkonen and Landrum 1994). This desorption process appears to be slow relative to the initial uptake of freely dissolved compound from the interstitial water. This mechanism would account for observations with field collected sediments containing environmentally resident contaminants (Kukkonen et al., 1993; Brunson et al., 1993) that exhibit kinetics curves similar to those in laboratory exposures (e.g., Landrum, 1989; Landrum and Robbins, 1990).

The bioavailability of contaminants may also change with concentration of the contaminant in the sediment due to differences in partitioning behavior of the compound. When sediment-sorbed pyrene was tested for toxicity and toxicokinetics, the uptake clearance was lower when *Diporeia* were exposed to sediments containing higher pyrene concentrations (Landrum et al., 1994). The pyrene distribution varied with concentration among sediment particles even after organic carbon normalization. This variation was thought to contribute to differences in bioavailability. The amount of variance based on differences in the relative bioavailability as a result of concentration of contaminants remains to be fully explored.

Complex chemistry and kinetics complicate interpretation of numerical criteria because of the absence of methodology for chronic bioassays to validate the utility of the criteria. Chronic bioassays are currently under development and should be available in the relatively near future to help demonstrate whether the criteria are adequate for long-term exposures. The absence of chronic bioassay validation is another reason for not using the criteria as clean-up criteria or for dictating remediation decisions.

Criteria have been set for only five compounds. Each of these compounds produces test organism mortality in 10 days within the aqueous solubility limit of the compound either in water-only exposures or as found in interstitial water. Compounds that do not produce effects within the aqueous solubility limit would require interpretation of hazard based on their bioaccumulation potential. Additional validation would be required to demonstrate the utility of the equilibrium partitioning approach for these compounds. Thus, the aqueous solubility limits may restrict the application of the equilibrium method for extending numerical criteria to other compounds.

In conclusion, the currently proposed numerical criteria should only be used to flag areas expected to exhibit impacts from toxic contaminants. The criteria can be used to restrict the disposal of contaminated sediment for open water disposal. However, the criteria should not be used as clean-up criteria and should not be used to determine whether or to what extent remediation is required. The variance in bioavailability among sediment, even after organic carbon normalization, and the absence of validation in chronic bioassays suggests that under some conditions the criteria may be under-protective or in some cases over-protective. As residue-based effects data become developed, such data can verify the bioavailability and potential impact at contaminated sites. This data will also aid in evaluating hazard to benthic populations and validate the criteria, particularly for chronic exposures.

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